SIGNAL PROCESSING V: Theories and Applications
L. Torres, E. Masgrau, and M.A. Lagunas (eds.)

ADAPTIVE BEAMFORMING WITH TEMPORAL AND SPATIAL REFERENCES IN SATELLITE COMMUNICATIONS

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ABSTRACT

This paper describes a structure for source tracking and interfering signals rejection in satellite communications. The configuration presented consists in a modified Generalized Sidelobe Canceller (GSC) which is provided with an additional loop for tracking. This loop uses a temporal reference therefore a reference signal must be available to the processor. Thus the proposed scheme combines spatial and temporal references in two separate adaptation loops.

The interferences rejection loop in the GSC has a much faster convergence that the tracking loop. Thus the latter one works with a signal free of interferences which have been rejected by the former one. The pointing erros in the GSC do not cancel the desired signal because of its extremely low signal to noise ratio as it usually happens in the satellite communication problem.

The used algorithm for tracking, the DSD, works well with initial pointing angles within the main lobe of the linear phased array.

INTRODUCTION

The term beamforming is used to describe some kind of spatial filtering that enhances a signal from a specific location while rejecting undesired signals from others locations. The antenna arrays are doubtless the most versatile antenna apertures in accomplishing any spatial filtering. In this case the beamformer appropiately combines the antenna array element outputs in order to provide the desired response. In conventional beamformers the element weights are data independent and they are chosen to obtain a pattern which is a trade-off between resolution in the desired direction and low side lobe elsewhere, mainly at the expected interferences. Adaptive beamformers, by the contrary, use weights which are data dependent and they are computed according to the statistics of the signals impinging on the array. These beamformers attempt to maximize the signal to noise and interference ratio by placing nulls in the directions of the interfering signals.

Data dependent beamforming requires some "a priori" information in order to achieve the optimum solution. The beamformer is able to work with two kinds of information: temporal and spatial reference. It is well known that the final performance of both beamformers is the same when both informations are exactly known, i.e., the desired signal direction is known or the temporal signal reference is a high quality estimation.

Nevertheless, in satellite communications the direction of arrival of the desired signal might be known with only a modest level of accuracy and the beamformer performance could be degraded.

With a temporal reference the shortcoming is related to the imperfections in the reference signal generation.

The performance of the two alternatives have been compared in [1] and the author suggests to use both kind of references altogether. The same author et al. [2] describe an algorithm that combines the features for a steered array and an array with a temporal reference. In [3] another combining array structure is proposed and the performance of the array as a function of the steering vector erros is examined.

The aim of this communication is also to use both informations in the same beamforming due to their complementarity. Both referencies would only

This work was partly supported by the PRONTIC Grant 105/88 and partly by ESA-ERA-CRISA under contract No. 8714/90/NL/US(SC).

known as much as a certain degree of accuracy. The beamforming configuration used is the Generalized Sidelobe Canceller (GSC) proposed by Griffiths and Jim [4].

GENERALIZED SIDELOBE CANCELLER

The GSC can be seen as an alternative formulation of the Linearly Constrained Adaptive Beamforming.

$$\underline{W}^H \underline{\underline{R}}_{xx} \underline{W} \,|_{min} \qquad (1)$$

subject to

$$\underline{\underline{C}}^H \underline{W} = \underline{f} \qquad (2)$$

Where $\underline{W}$ is the weight vector and $\underline{\underline{R}}_{xx}$ is the covariance matrix. The matrix $\underline{\underline{C}}$ and vector $\underline{f}$ define the constraints.

Nevertheless the GSC structure presents some advantages in the implementation of a wide variety of linearly constrained adaptive arrays.

The general structure is shown in figure 1.

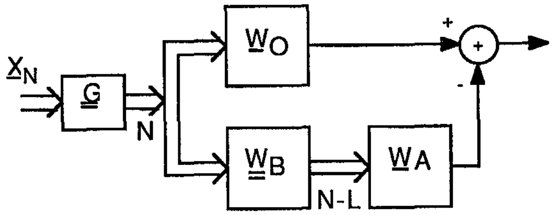

Fig. 1. Generalized Sidelobe Canceller

$\underline{X}_N$ is the input data vector to the GSC coming from the array elements. The matrix $\underline{\underline{G}}$ is a pre-processor (which consists in general in time-delay steering elements in the wide band problem or linear phase shifts in the narrowband case) used to steer the array in the direction of interest. The beamforming weight vector $\underline{W}_0$ along with the prefilter $\underline{\underline{G}}$ gives the quiescent beam pattern

$$\underline{W}_q = \underline{\underline{G}}\, \underline{W}_0 = \underline{\underline{C}}(\underline{\underline{C}}^H \underline{\underline{C}})^{-1} \underline{f} \qquad (3)$$

Where $\underline{\underline{C}}$ and $\underline{f}$ are the constraint matrix and vector respectively.

With only desired signal direction constraint and narrowband beamforming the $\underline{W}_0$ vector components are all the unity.

In the lower path the matrix $\underline{\underline{W}}_B$ is fixed and it is orthogonal to the matrix $\underline{\underline{C}}$. This matrix block the desired signal flow when there are no pointing errors. This matrix also has a very simple form in the above conditions and is independent on the steering angle. $\underline{W}_A$ is the unconstrained adaptive weight vector.

GENERALIZED SIDELOBE CANCELLER WITH SPATIAL AND TEMPORAL REFERENCE

The configuration proposed is depicted in figure 2.

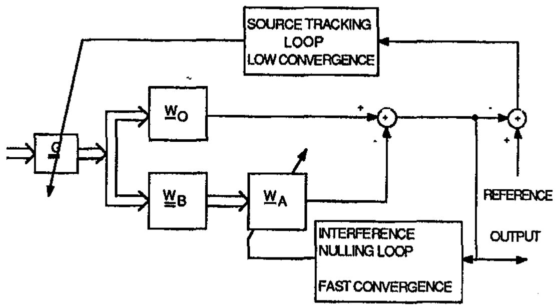

Fig. 2. Generalized Sidelobe Canceller with Spatial and Temporal Reference

As it can be seen it is a modified GSC structure which includes an additional loop for tracking purposes.

The weight vector $\underline{W}_A$ in the lower path of the GSC has to be adapted in accordance with the interfering signals impinging on the array. This adaptation is free of constraints and any adaptive algorithm can be used. The updating of $\underline{W}_A$ has to be done very fast in order to have the output free of interferences when the tracking loop starts to work. The operation mode of the former loop is as follow. When the desired signal direction of arrival (DOA) starts moving, clearly the beamformer has to modify the prefilter matrix $\underline{\underline{G}}$. This is accomplished by minimizing the difference between the beamformer output and the reference signal by changing the previous DOA of the desired signal source. (Note that only the parameters corresponding to the angular location have to be changed). There are many possible search algorithms for updating the DOA. The gradient search or steepest descent algorithms can be used. These algorithms are well-known but their drawback is that the mean square error as a function of the angular parameter is not a quadratic surface and little can be said about the convergence properties. Furthermore the surface can not be unimodal and the algorithm could reach a local minimum. In this case it might be reasonable to use random search algorithms.

SIMULATION RESULTS

Some numerical examples are presented here to illustrate the performance of the proposed scheme. The signal environments were composed in all the cases by the desired signal and an interfering signal. The signal to noise ratios were 0dB a 20dB respectively. The algorithm used to update the $\underline{W}_A$in the GSC was the normalized LMS and the algorithm for source tracking the Differential Steepest Descent (DSD). The array was a linear one composed by 10 omnidirectional equispaced elements and only one direction constraint was considered.

Figures 3(a) and 3(b) present the results obtained for the acquision operation mode. The desired and interference signals come from 30^o and -45^o, respectively. The initial steering angle in matrix $\underline{\underline{G}}$ was 24 degrees. Fig. 3(a) shows the time evolution of the steering angle and fig. 3(b) the output powers of the desired and interference signals. It could seem that there is a great residual variance in the pointing angle error but the desired signal output power remains practicaly constant along the time as the fig. 3(b) shows. The interfering signal stays below the white noise in average.

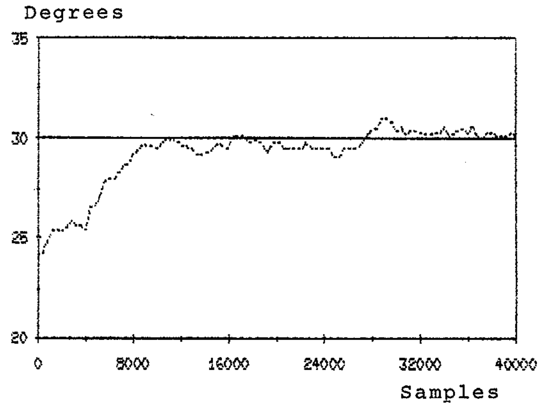

Fig. 3(a). —— Desired signal direction.
----- Array pointing angle.

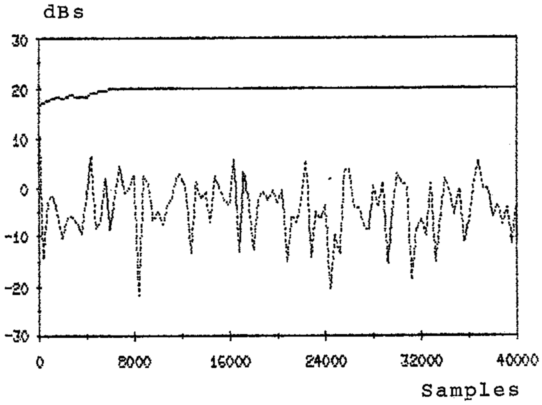

Fig. 3(b). —— Desired signal output power.
----- Interference output power.

Fig. 3. Acquisition mode.

The source tracking is depicted in figures 4(a) and 4(b). The conclusions are similar to the angle acquisition mode. The algorithm follows quite well the desired signal direction and the output power is constant all the time. Again the interference signal power drops bellow the white noise.

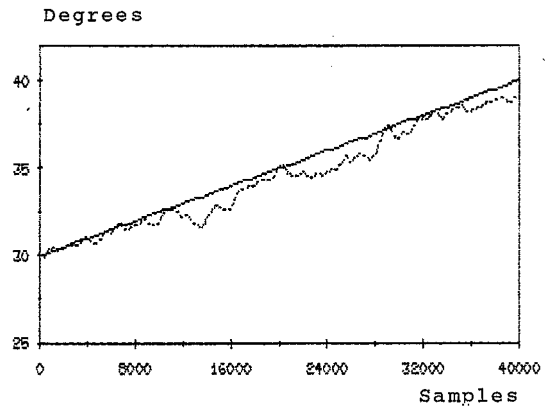

Fig. 4(a). —— Desired signal direction.
----- Array pointing angle.

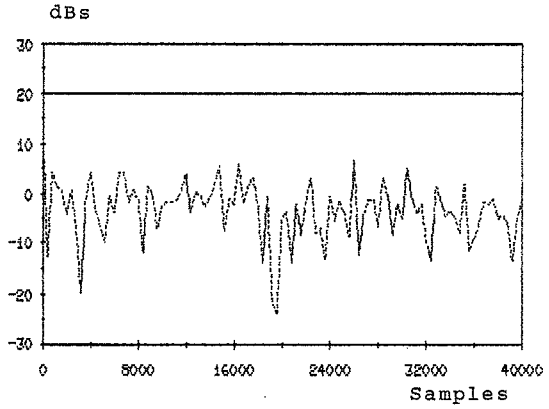

Fig. 4(b). —— Desired signal output power.
----- Interference output power.

Fig. 4. Tracking mode.

CONCLUSIONS

A scheme for source tracking and interferences rejection has been presented. It is based on the Generalized Sidelobe Canceller to which a tracking loop has been added. The simulation results show that the algorithm performs quite well in the acquisition and tracking modes. Further researches will be done in order to gain more insight and improve the performance of the structure presented. There are several parameters to consider in the DSD algorithm (the angular perturbation, the step size and the number of samples for computing the mean square error used in the gradient estimation) and some analytical studies have to be carried out to get design guiding lines of these parameters.

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